TRANSFER COEFFICIENTS IN COOLER-CONDENSERS

BY

DAVID LEE McKINLEY

B.S., Carnegie Institute of Technology, 1949
M.S., University of Illinois, 1950

AN ABSTRACT OF A THESIS

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN CHEMICAL ENGINEERING
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ACKNOWLEDGMENT

Th author wishes to express his appreciation to Dr. H. F. Johnstone for his guidance and assistance in the direction of this research. Appreciation is also expressed to W. B. Retallick for assistance in the experimental work and calculations. The author is grateful to the Texas Gulf Sulphur Company for the support of a research assistantship for two years, and to the General Electric Educational Fund for a Gerard Swope Fellowship which he held for the third year of graduate work.

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Introduction

Although a large amount of data have been accumulated on the operation of cooling towers, few studies have been made on the performance of direct contact dehumidifiers or cooler-condensers for substances other than water. The use of indirect contact condensers for the removal of a condensible vapor from an inert gas often requires alloy construction and provides low heat transfer coefficients, resulting in large and expensive equipment. The high rates of heat and mass transfer obtainable when the gases and cooling liquid are brought into direct contact make these devices attractive in many cases. Examples of the commercial use of cooler-condensers in industry are found in the removal of sulfur vapor from the catalytic oxidation of hydrogen sulfide and in heat recovery systems from blow gases in pulp mills.

Much of the present work was on evaluation of the effectiveness of a packed column for the dehumidification of gases containing either water or dibutylphthalate vapor by contact with the cooled recirculated condensates. This was done by measuring individual coefficients of heat and mass transfer and overall coefficients of enthalpy transfer. The individual coefficients for the water system were calculated from the rate data by a modification of the enthalpy potential method proposed by Mickley (1). This method breaks down when the gas stream becomes saturated. In such cases, overall coefficients of enthalpy transfer were used to evaluate the performance of the tower. Measurements were also made on rates of humidification in the two systems.

In a dehumidifier, or cooler-condenser, fog is often formed by condensation of the vapor at some point in the gas stream rather than on the cooling surface. The fog passes out of the condenser with the inert gas and frequently results in a loss of valuable or obnoxious material unless a fog removal

device is used. When fog is formed, the coefficients of heat and mass transfer for the gas film are different from those under non-fogging conditions. The coefficients were measured under the two conditions to determine the exact effect.

Experimental

The coefficients of heat and mass transfer were determined for a column one foot square packed with refractory Drip Point Grid Tile to a height of 2.25 feet. Observation of fog was made through windows above and below the packed section. The liquid flowing through the tower was distributed over the top of the packing by an eighteen point distributor equipped with splash plates. The packed column was located on top of a reservoir which served to collect the liquid flowing from the tower. The reservoir was equipped with coils for cooling and heating to regulate the temperature of the liquid before recirculation. A centrifugal pump immersed in the liquid in the reservoir was used to circulate the liquid.

The inlet gas was either air or hot flue gases produced by a refractory lined burner in which natural gas was used as fuel, or a combination of the two. For the work on dehumidification of gas containing water vapor, the inlet gas humidity was regulated either by spraying water into the hot burner gases or by injecting steam into the gas stream. The water spray also served to regulate the temperature of the inlet gas. Provision was also made for adding condensation nuclei to the inlet gas. For the work on condensation of dibutylphthalate the inlet gas composition was maintained by injecting liquid dibutylphthalate into the throat of a venturi through which the hot gases from the burner passed. The liquid was pumped to the venturi by a positive displacement gear pump. Water was sprayed into the inlet gas stream for temperature control. Because the entire system for the work on dibutylphthalate was kept above the dew point of the water vapor content of the gas stream, the water from combustion and the sprays constituted a part of the inert, or carrier gas.

In the water-gas system the vapor content of the inlet and

exit gases was determined gravimetrically by passing samples of the gas through a glass condenser and drying tube to remove the water and thence through a wet-test meter. Where the presence of fog resulted in a humidity greater than the saturated composition, the saturated composition corresponding to the gas stream temperatures was used as the gas composition and all excess water above this was assumed to exist as fog. For the work with dibutylphthalate, the inlet gas composition was determined from the rate of flow of inert gas and the rate of injection of dibutylphthalate. The exit gas was always saturated and for all the dehumidification runs contained appreciable quantities of fog in which case the saturated composition at the exit gas temperature was taken as the gas stream composition.

All gas and liquid temperatures were measured by thermocouples, the exit gas temperature by a high velocity thermocouple, and the inlet gas temperature by a thermocouple located in a heated section of the inlet gas duct kept at the same temperature as the gas in order to eliminate conduction and radiation errors.

Conclusions

For the individual film coefficients for heat and mass transfer calculated from the rates of dehumidification of high temperature humid gases by direct contact with water, it was found that the liquid film resistance to heat transfer was always less than ten percent of the combined resistance of both phases. It was observed that fog formation can occur in a packed column before the bulk of the gas becomes saturated, thus verifying the concept of the limiting conditions under which fog formation is possible as developed in previous work (2). The overall enthalpy transfer coefficients were the same for humidification and dehumidification when converted to the same conditions of temperature and flow rates. When fog was present over the entire height of the packing the coefficients of enthalpy transfer were nearly twice as great as when no fog was present, and the increase in the

coefficients was independent of the amounts of fog present. When fog was formed only at the top of the tower by contact of the hot saturated gases with cold liquid, however, the observed enthalpy transfer coefficients were not affected within the accuracy of the measurements.

The presence of fog also increased the enthalpy transfer coefficient in the condensation of dibutylphthalate vapor from an inert gas by direct contact with cold dibutylphthalate liquid, although the increase was not as large as in the case of water. The measurements made on the cooling and dehumidification of hot gases containing vapors of dibutylphthalate, and on cooling hot dibutylphthalate liquid by evaporation into air, were analyzed by a modification of the Mickley method developed to permit calculation of individual film coefficients for organic vapor-inert gas systems. The conditions studied permitted the calculation of the overall enthalpy transfer coefficients only, and, because of the low volatility of dibutylphthalate, most of the enthalpy transferred was sensible heat.

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VITA

The author was born on February 29, 1928 in Meadville, Pennsylvania. After graduating from Meadville High School in 1945, he entered Allegheny College majoring in chemistry. In 1947 he transferred to the Carnegie Institute of Technology majoring in chemical engineering. He received the Bachelor of Arts Degree in Chemistry and the Bachelor of Science Degree in Chemical Engineering from the respective schools in 1949. He entered the Graduate College of the University of Illinois and received the Master of Science Degree in Chemical Engineering in 1950. From 1949 to 1951 he held the Texas Gulf Sulphur Company research assistantship. He was awarded a Gerard Swope Fellowship by the General Electric Educational Fund for the third year of his graduate work in 1951-1952.